A Review on Radar Applications in Civil Aviation

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Abstract

Radio Detection and Ranging (RADAR) systems have been evolving very quickly in the past decades. Aeronautical and aviation industries are highly dependent on radar systems whose evolution rate is very high. Indeed, modern radar systems help air traffic controllers work efficiently, and these modern systems considerably reduce maintenance costs. Therefore, not using the most current radar systems in the airports means performance of aviation missions are not as efficient as they might be. Moreover, surveillance of aircraft in different phases of flight or in Instrument Flight Rules (IFR) is almost impossible in the absence of radars. To elaborate the application of aviation radar systems various companies and organizations have employed different names for radar systems. In this paper, these radar systems are distinguished, and then each of them are described individually to provide a better scope for the readers. Classification of the ground-based and airborne civil aviation radars has been carried out based on the task they perform to help provide safe flights. General description of each category, its function, and its system specifications are comprehensively discussed afterward. Finally, an example of the most current radar system is brought to give a better understanding of the latest radar systems.

Keywords: *Radar-aviation-aircraft-surveillance-application*

1. Introduction

Continuing increase in air traffic density has led to the use of different radar systems for different tasks at major centers in order to relieve the strain on air traffic controllers. In general, air transport radars are used for monitoring, controlling, and navigating the aircraft in both air route and terminal areas to perform a safe flight. Another application that radars are used for is to detect hazardous weather phenomenon ahead or near the aircraft. Aviation radar systems are either ground-based or based in the aircraft.

This paper categorizes different types of radars which are used in aviation and briefly reviews radars associated with each category. It is noted that radars can be categorized based on several aspects but this paper categorizes civil aviation radars with regard to their applications (not the radar technologies).

This paper is organized as follows. In the next section, ground based radars are discussed. This category includes four types of radars including Air Traffic Surveillance Radars, Precision Approach Radar (PAR), Surface Movement Radar (SMR), and Ground Meteorological Radars. The airborne radars are discussed in section 3. This category includes Airborne Weather Radar (AWR), which provides indication of the weather ahead of the aircraft, and the Radio Altimeter, which calculates the height beneath the aircraft. Finally, a brief conclusion is presented.

2. Ground-based Radars

2.1. Air Traffic Surveillance Radars

Air Traffic Surveillance Radars are of two generic types, namely, Airport Surveillance Radar (ASR) and Air Route Surveillance Radar (ARSR) also known as En-route radars. Both groups are a combination of Primary Surveillance Radar (PSR) and Secondary Surveillance Radar (SSR). Each of them, nevertheless, may be used individually in some special cases. PSRs are those that rely on the radiated microwave energy reflected from the skin of aircraft for their detection. In contrast, SSRs work in conjunction with transponders located on aircraft [1].

Primary Surveillance Radar (PSR)

PSR is a conventional radar sensor that illuminates a large portion of space [2]. It is used mainly for approach and en-route surveillance [3]. Equipped with a continually rotating antenna, PSR sends out a beam of energy. When that beam of energy hits an aircraft, its echo is reflected back to the same radar unit. By measuring the time it takes for the beam to be reflected back and the direction the reflection comes from, the PSR can determine the position of the aircraft. The position is sent to the Air Traffic Control (ATC) system where it is displayed to the air traffic controller as a radar blip [3]. This type of radar uses low vertical resolution antenna but good horizontal resolution. It quickly scans 360 degrees around the site on a single elevation angle. It can thus give the distance and radial speed of the target with good precision but requires often one or more radars to obtain the vertical position and the actual speed [2]. The undisputable advantage of the PSR is that it detects all aircraft in range regardless of aircraft on-board equipment. This is referred to as independent surveillance. This means that no aircraft can remain invisible to air traffic controllers. There are adequate pros for using PSR such as no need to additional on-board equipment for detection, and high data integrity level, low infrastructure costs (one site installation). However, there are some cons such as not being able to identify the aircraft and having a limited range, a low update range, low efficiency in mountainous areas, and high equipment cost [3].

The frequency band 2700 – 2900 MHz, and to a lesser extent the band 2900 – 3300 MHz is heavily used for PSR mainly providing medium range (to about 60 NM) independent non-cooperative surveillance. These radars typically provide surveillance in terminal and approach areas around major airports. The band 2700 – 2900 MHz is also used for meteorological radar [4 pp. 7-111]. The frequency band 2700-3300 MHz is extensively used for PSR (10 cm) for medium-range, en-route surveillance as well as for terminal area and approach monitoring [4pp. 7-111]. Ten-centimeter radar (2700-3300 MHz) technologies and practices date from the 1940s and modern versions employ the latest radar techniques for plot extraction and display on formatted synthetic displays. Frequency diversity and pulse compression techniques are used to extract weak echoes from interference and to improve range resolution. Multiple frequency operation, commonly using two to four frequencies separated by 60–100 MHz, is necessary and requires careful frequency planning and separation of stations. More stable solid-state transmitter frequency control is leading to a more effective use of spectrum than older magnetron systems, although the latter systems still have many years of useful life [4pp. 7-112].

On a global basis, the band 1300 – 1350 MHz (and in many countries also the band 1215 – 1300 MHz) is also used for PSR, mainly providing long-range independent non-cooperative airspace surveillance [4pp. 7-83]. The band 1300-1350 MHz is used extensively for 23 cm (IEEE L-band (1-2 GHz)) PSRs, for both terminal and mostly en-route surveillance tasks. Modern systems employing digitized plot extraction often operate on multiple frequencies and use Pulse Repetition Frequency (PRF) discrimination where up to four or even six frequencies may be used by a single radar spaced over a band of 100 MHz For these requirements, the band from around 1215 to 1370 MHz must be available [4 pp. 7-83-84].

Secondary Surveillance Radar (SSR)

SSR is a radar system used in ATC used for both approach and en-route surveillance. It detects and positions the aircraft and receives additional information such as their identity and altitude [3] by transmitting coded interrogations to aircraft transponders in various modes [5] [6]. The transponders of SSR receive the radar's transmitted signal and radiate coded signals for reception by the radar receiver. As the power radiated by the transponder is far more than the feeble echo from the aircraft skin, SSRs can 'see' out to longer ranges with less transmitted power than PSRs. Further, the coded response by the transponders conveys many types of useful information such as aircraft identification and altitude. Indeed, the development of the SSR, also called the Air Traffic Control Radar Beacon System (ATCRBS), was a major milestone in the evolution of ATC technology [1].

SSR employs three main modes. It uses Mode A for transmitting identification and Mode C for transmitting pressure-altitude information. Mode S employs selective addressing of the aircraft and has a limited data link capability [5 pp. 7-3].

SSR installations operate on 1030 MHz for the ground-to-air interrogation signal, and 1090 MHz for the air-to-ground reply. Extensive use of pulse repetition frequency (PRF) discrimination and plot plan processing techniques assists in reducing the number of invalidated responses being processed by the ground receiving system [6]. Compared with PSR, the advantages of SSR can be summarized as follows: increased range for lesser-transmitted power, no clutter from weather or permanent echoes on the Plan Position Indicator (PPI), positive identification without aircraft maneuvers, reduction of receiver/transmitter messages for identification, and air-to-ground information link. Thus, with the implementation of SSR, important facilities are available to the controller, the most significant being positive identification, automatic altitude information and aircraft emergency indication. SSR is the most positive source of information likely to be generally available to ATC in the next decade [7]. In most airports SSR and PSR are mostly co-located. These Secondary Surveillance Radar co-located SSR and PSR are often employed with combined plot extraction, electronic processing and display. Electronically generated labels displaying flight number and other data, i.e. altitude reported from SSR Mode C, are often added to provide a complete radar data picture. Twenty-three cm is the preferred wavelength for long-range radar where a sufficiently large antenna can be installed to provide narrow beams in azimuth and phased arrays for beam switching for multi-purpose mode operation [4 pp. 7-83-84].

2.1.1. Airport Surveillance Radar (ASR)

ASR is a control radar used to detect and display an aircraft's position in the terminal area [8]. ASR has a predominant role in aircraft position determination and separation during the approach control phase [1]. The sophisticated systems at large airports consist of two different radar systems, PSR and SSR. The PSR typically consists of a large rotating parabolic antenna dish that sweeps a vertical fan-shaped beam of microwaves around the airspace surrounding the airport. The SSR consists of a second rotating antenna, often mounted on the primary antenna, which interrogates the transponders of aircraft, which transmits a radio signal back containing the aircraft's identification, barometric altitude, and an emergency status code, which is displayed on the radar screen next to the return from the PSR [2]. The positions of the aircraft are displayed on a screen; at large airports on multiple screens in an operations room at the airport called in the US the Terminal Radar Approach Control (TRACON), monitored by air traffic controllers who direct the traffic by communicating with the aircraft pilots by radio. They are responsible for maintaining a safe and orderly flow of traffic and adequate aircraft separation to prevent midair collisions [2]. These radar sets operate usually in IEEE S-band (2 to 3 GHZ), and are capable of reliably detecting and tracking aircraft at altitudes below 25,000 feet (7,620 meters) and within 40 to 60 nautical miles (75 to 110 km) of their airport. The antennas of ASR rotate at 12 to 15 revolutions per minute to ensure the required data renewal rate of up to 5 seconds [9]. Modern ASR have an additional weather channel and can clear up dangers for aviation weather conditions [8].

ASRs have undergone continuous evolution during the decades of their operation. The most sophisticated in the series of radar types is the ASR-12 of the United States, which has significantly improved more than the ASR-7, ASR-8, and ASR-9 radars [1]. ASR-11 is an integrated PSR and SSR system that has been deployed at terminal air traffic control sites. It interfaces with both legacy and digital automation systems and provides six-level national weather service calibrated weather capability that provides enhanced situational awareness for both controllers and pilots [10]. The PSR of ASR-11 uses a continually rotating antenna mounted on a tower to transmit electromagnetic waves that reflect, or backscatter, from the surface of aircraft up to 60 miles from the radar. The radar system measures the time required for radar to echo to return and the direction of the signal. From this, the system can then measure the distance of the aircraft from the radar antenna and the azimuth, or direction, of the aircraft in relation to the antenna. The primary radar also provides data on six levels of rainfall intensity and operates in the range of 2700 to 2900 MHz. The transmitter generates a peak effective power of 25 kW and an average power of 2.1 kW. The average power density of the ASR-11 signal decreases with distance from the antenna. At distances of more than 43 feet from the antenna, the power density of the ASR-11 signal falls below the maximum permissible exposure levels established by the Federal Communications Commission (FCC). The secondary radar of the ASR-11 uses a second radar antenna attached to the top of the primary radar antenna to transmit and receive area aircraft data for barometric altitude, identification code, and emergency conditions. Military, commercial and some general aviation aircraft have transponders that automatically respond to a signal from the secondary radar by reporting an identification code and altitude. The air traffic control uses this system to verify the location of aircraft within a 60-mile radius of the radar site. The beacon radar also provides rapid identification of aircraft in distress. The secondary radar operates in the range of 1030 to 1090 MHz Transmitting power ranges from 160 to 1500 watts [11].

2.1.2. Air Route Surveillance Radars (ARSR)

ARSR also known as En-route Radar is a PSR that is coupled to an SSR [8]. ARSR monitors the air traffic outside the special airfield areas. These radar sets detect and determine the position, course, and speed of air targets in a relatively large area. Typically, the range of ARSR is approximately 370 km (200 NM) [5]. ARSRs is the key system that helps maintain separation among en-route aircraft. Relative to the ASRs these radars have high transmitted power, low pulse repetition frequency, and large and slowly scanning antennas, providing a longer operating range of the order of 450 km. ARSR-2 and ARSR-3 are currently used radars in this category, and ARSR-4 is the most modern system in the series [1].

ARSR-4 is a coherent, three-dimensional, solid-state, unattended, long range surveillance radar operating in IEEE L-Band (1-2 GHz). The military nomenclature of the ARSR-4 is the AN/FPS-130. The ARSR-4 generates dual stacks of elevation beams for optimum time energy management. The wideband antenna with multiple and selectable receive beams (dual stacks of elevation beams) aid reducing false targets. The array-fed aperture provides azimuth side lobes below -35 dB, and circular polarization to enhance detection of aircraft in weather. The solid-state transmitters waveform is intra-pulse modulated with non-linear frequency modulation. The pulse is divided into 2 sub pulses that are transmitted in different carrier frequencies (frequency diversity). The radars accuracy is in range 1/16 NM (116 m); in bearing 0.176 degrees, and in height 3000 ft. (914 m). Eight pulse Doppler filters suppress clutter out to 400 km (216 NM). The modular digital target extractor and tracker is designed to process 800 aircraft plus 200 non-aircraft reports per scan, with a 50 per cent reserve capacity, and is expandable to greater capacity. ARSR-4 also provides weather processing of six levels. The transmitter is located below the rotary joint allowing repair to occur while the system is in operation. Built-in automatic reconfiguration, reserve capacity and redundancy contribute to high availability. The system is unmanned with remote control and monitoring and remote fault detection and analysis. En-route air traffic in the U.S. is tracked by forty-four ARSR-4 radars along the borders and coasts [8]. Table 1 shows technical data of ARSR-4 developed by Northrop Grumman Corp [12].

2.2. Precision Approach Radar (PAR)

PAR is a ground-based radar system for providing surveillance to support precision approach to aircraft and to detect traffic at airports [4 pp. 7-150]. PAR was designed in the 1940s as an aid to landing in all weather conditions. However, the landing guidance function was subsequently taken over largely by the Instrument Landing System (ILS) (and more recently by the Microwave Landing System (MLS)), because of their mobility PARs are still in use in some countries [1].

PAR provides lateral and vertical guidance to an aircraft pilot for landing, until the landing threshold is reached. After the aircraft reaches the Decision Height (DH) or Decision Altitude (DA), guidance is advisory only. Controllers monitoring the PAR displays observe each aircraft's position and issue instructions to the pilot that keep the aircraft on course and glide path during final approach. Air traffic controllers must transmit a minimum of every 5 seconds to the pilot their relation to the azimuth portion and, once intercepting the glide path, their elevation. One type of instrument approach that can make use of PAR is the Ground-Controlled Approach (GCA). The GCA is a control mode in which an aircraft is able to land in bad weather conditions.

Table 1: Technical data of ARSR-4

characteristic	
Frequency	1215 to 1400 MHZ
Waveform	NLFM 150 µs pulse
Peak power	65 kW
Avg. power	3.5 kW
Range (1m^2 target)	463 km (250 nm)
Accuracy	116 m (1.16 nm)
Resolution	323 m (1.8 nm)
Azimuth	360º
Accuracy	0.176º
Resolution	1.5º
Height	30480 m (10000 ft)
Accuracy	914 m (3000 ft)
Elevation	-7º to 30º
MTBF	1500 hr.
Availability	0.99742
Fault detected	98%

The pilot is guided by ground control using PAR. The guidance information is obtained by the radar operator and passed to the aircraft by either voice radio or a computer link to the aircraft [9]. The approach is terminated when the aircraft reaches the OCA/H (Obstacle Clearance Altitude/Height). Nevertheless, information is provided until threshold and aircraft may be monitored by controller until touchdown. Controller in charge of PAR should not be responsible for any duty other than the PAR approach concerned [2]. PAR operates in bands 9000 – 9200 MHz and 15.4 – 15.7 GHz. However, use of PAR sets in IEEE X-band (8 to 10 GHz) which means the first band mentioned is more common [4 pp. 7-136]. Parameters of a modern PAR system developed by ELDIS radar system are brought in table 2 [13].

2.3. Surface Movement Radar (SMR)

SMR, also known as Airfield Surface Movement Indicator (ASMI) and Airport Surface Movement Radar (ASMR) [14 pp. 201], scans the airport surface to detect all principal features on the surface of an airport, including aircraft and vehicular traffic, and presents the entire image on a radar indicator console in the control tower for air traffic controllers [8].SMR technology has evolved over the years as part of an effort to mitigate runway incursion risks and enhance airport capacity. SMR systems of various types have been installed in major airport as early as the 60s, and have kept evolving [15]. SMR has historically been known by other names such as ground movement radar, Airport Surface Detection Equipment (ASDE) and airfield surface movement indicator. SMR, however, is part of the more advanced ASDE modes now [16]. SMR is typically presented as a video blip, overlaid onto a plan view map of the airport showing features such as the runways and taxiways, grass areas, and buildings. Data processing capabilities that are offered in conjunction with this radar may include runway incursion and conflict alert, and target identification and labelling. SMR may also be used at nighttime and during low visibility conditions and bad weather to monitor the movement of aircraft and vehicles. SMR provides surveillance cover for the maneuvering area, which is defined as that used for the take-off, landing and taxiing of aircraft, excluding aprons [8]. ASDE utilizes SMR data to monitor the movement of aircraft and vehicles on the maneuvering area, and to provide routing information to pilots and vehicle drivers as necessary. It also provides advice and assistance for the safe and efficient movement of aircraft and vehicles on the maneuvering area in the permanent absence of visual observation of all or part of the maneuvering area [17].

Table 2: PAR-E system parameters

characteristic	
Frequency band	X-band
Instrumented range	40 km (21.6 nm)
Instrumented azimuth	-15° to +15°
Instrumented elevation	-1° to +14°
Data Refresh Rate	< 1 s
Azimuth antenna vertical ilt mechanism	-2° to +3° around optimal setting
Elevation Antenna skew mechanism	-10° to +10° around azimuth scan centerline

The most recent system currently being deployed in the US by the FAA is the ASDE Model X (ASDE-X) system. In this system the SMR is one of several sensors that are used in addition to transponder multi-lateration and GPS-based position reports, referred to as Automatic Dependent Surveillance – Broadcast (ADS-B); however, the SMR is a key subsystem [15]. SMR also forms a key element of Advanced-Surface Movement Guidance and Control System (A-SMGCS) which comprises of a combination of systems that provide services to aircraft and vehicles in order to maintain airport throughput under all local weather conditions, whilst maintaining the required level of safety [2]. Role of SMR is to provide surveillance of all aircraft and vehicles in the airport with a high update rate. SMR antennas are often mounted on the tower, which has good visibility of the maneuvering area. The ground surface environment is quite different from high altitude because of the increased clutter and other physical problems. The quality of surveillance information on the ground is often quite poor and limited by these physical problems [8]. In contrast to using of PSR that means target labelling may not be possible, and hence controllers should use visual identification of aircraft (by looking out of the tower window) using SMR is a contributing factor to counter the reduced capacity of airports in low visibility conditions [8]. According to reference [4], however, SMR systems can be supported by band 31.8–33.4 GHz, they mostly operate in IEEE X-band (8-12 GHz) - or Ku-band (12-18 GHz). The higher frequency provides greater target resolution although performance in precipitation, such as rain and fog, is inferior [4 pp.7-166]. The antenna rotation speed of SMR is 60 revolutions per minute [8]. Table 3 compares Azimuth beam width and elevation beam width for both X-band and Ku-band [15].

Table 3: Beam width of X and Ku band SMR

Band	Azimuth beam width	Elevation beam width
X-band	0.35 degrees	10 degrees
Ku-band	0.25 degrees	1.6 degrees

The SMR developed by EASAT radar systems is a good example of the current Surface Movement Radar systems. The system gives frequency selection across 9.0 to 9.5GHz IEEE X-Band range for maximum flexibility. The power produced by the system is about 180W. This radar system can also detect the surface of the airport with the range cell size of 3m. There are three types of antennas offered by EASAT Radar Systems for this radar system. The first is a linear array antenna with the length of 7.4m, the second benefits from the ‘Anti-Icing’ characteristic with the length of 7.8 m. Finally, size of the third antenna is 5.5m considering that it is a reflector type antenna [18].

2.4. Ground Meteorological Radars

Two types of ground meteorological radars (weather radars) are distinguished in the air transport. The first being the airborne weather radar (will be discussed comprehensively in section 3.1), which evaluates meteorological situation ahead of the flying aircraft and ground meteorological radio locator, which observes meteorological situation in the vicinity of the airport being the second type. As for the operation principle and method of observation of meteorological situation, the second weather radar type is used not only at the airports but also for the observations of weather over the large territories of particular countries [19]. Ground meteorological radars associated with aviation are categorized in two different sections. The first section provides information on Terminal Doppler Weather Radar (TDWR) and the second section gives data on how Microburst Radar (MBR) works. Both radars are employed to indicate the presence of wind shear and gust fronts and other hazardous weather phenomena in the vicinity of the airports. However, MBR is a shorter-range system since it has to observe weather phenomenon only at low altitude. It is also noteworthy that another radar system known as Next Generation Weather Radar (NEXRAD) or technically called Weather Surveillance Radar, 1988 Doppler (WSR-88D), is used for safe flight of the aircrafts, but this radar system is not basically designed for air transport services. Thus, after discussing TDWR, NEXRAD is compared with TDWR in this paper.

TDWR is specially designed to detect dangerous microbursts. It is similar in principle to NEXRAD but is a shorter-range system since it has to observe dangerous weather phenomena only in the vicinity of an airport [10].

2.4.1. Terminal Doppler Weather Radar (TDWR)

TDWR is a radar system with a three-dimensional "pencil beam” designed to detect hazardous wind shear conditions, precipitation, and winds aloft on and near major airports situated in climates with great exposure to thunderstorms in terminal of the air traffic control areas. It is a fully coherent, high-sensitivity, high-resolution radar using a klystron transmitter tube [2].

The TDWR measures winds, turbulence, and storm formations in and around an airport as often as once every minute. The Doppler-effect allows the system to detect the movement of air masses that can form into a wind shear or a microburst. The data processing algorithms are predictive and designed to forecast the development of microburst phenomena and project wind direction shifts. TDWR is not dependent on precipitation to determine the existence of weather activity. The Doppler radar processes detected microscopic dust particles and insects to determine wind speed and direction [8].

The primary advantage of TDWRs over previous weather radars is that it has a finer range resolution—meaning it can see smaller areas of the atmosphere. The reason for the resolution is that the TDWR has a narrower beam than traditional radar systems, and that it uses a set of algorithms to reduce ground clutter.

Table 4: Comparison of TDWR and WSR-88D

	WSR-88D	TDWR
Wavelength	10 cm	5 cm
Volume Scan Time	4 minutes in VCP 12	1 min 0.2 degree, HAZ
Beam Width	1.25 degrees	0.5 degrees
Range Gate	0.13 nm in velocity 0.54 nm in reflectivity	0.067 nm
Max Unambiguous Velocity	Up to 62 kts	20-30 kts
Max Doppler Range	230 km	90 km

TDWR operates in IEEE C-Band (4 to 8 GHz) especially from 5.60 to 5.65 GHz (C band) to avoid interference with the lower frequencies of NEXRAD and ASR systems [10]. TWDR Antenna is an all-aluminum, solid surface, 25-foot reflector designed for both outdoor and radome environments [8]. The range resolution of the TDWR is finer than what is available in the NEXRAD, or any other FAA radar that has weather channel capability. The TDWR utilizes a range gate resolution of 150 m for Doppler data. It has a resolution of 150 m for reflectivity data within 135 km and 300 m from beyond 135 km to 460 km. By contrast, the NEXRAD has a maximum range gate resolution of 250 m for Doppler and 1 km for surveillance data. The angular (azimuth) resolution of the TDWR is nearly twice what is available in the NEXRAD. Each radial in the TDWR has a beam width of 0.55 degrees. The average beam width for the NEXRAD is 0.95 degrees. Table 4 shows a comparison of technical specifications between the TDWR and the WSR-88D [2].

2.4.2. Microburst Radar (MBR)

MBR is a ground-based system that detects microburst wind shear before a hazardous condition occurs. This early warning is between two to five minutes and it provides pilots with sufficient time to direct aircraft away from imminent microburst danger. By detecting and continuously tracking the precursors of microburst formations, the MBR detects when and where a hazard will take place. The MBR surface wind shear detection capability indicates the existence of hazardous wind shear regions at low altitude. As per the requirements of the US Federal Aviation Administration, the critical area for microburst detection covers runways themselves, and includes 3 miles (5 km) on the approach side and 2 miles (3 km) on the departure side of each runway [20]. These are areas where the aircraft is likely to be below 1000 ft. in altitude and hence subject to microburst-induced wind shear. Further, at least 90% of the microbursts in the vicinity of the airport must be detected with a false alarm rate not exceeding 10% [1].

Developed by Lockheed Martin, the MBR receiver/transmitter is a modified version of a solid-state, commercial IEEE X-Band (8-12 GHz) airborne weather radar, 10 inches wide, 8 inches high, and 13 inches long. The radar antenna consists of a small linear phased array that is electronically scanned in elevation (for downdraft detection aloft) and a flat plate pencil beam antenna that is fixed in elevation (for microburst surface outflow detection). This compact antenna is mechanically rotated in azimuth. The peak power of the system is 80 watts and its average power is 4 watts. Instrumented range of MBR is reported 12 nautical miles with the antenna rotating 3 rpm [8].

3. Airborne Radars

3.1. Airborne Weather Radar (AWR)

AWR is a sort of airborne radar which provides visual indication of the intensity of convective weather inside the aircraft. The radar information is displayed on a dedicated unit or shown (on modern aircraft) in combination with the aircraft route on the EFIS Navigation Display (ND) [14 pp. 207]. The system can also predict the presence of wind shear ahead of the aircraft. Current Airborne Weather Radars, which are mostly Doppler radars, are also capable of detecting the motion of rain droplets in addition to intensity of the precipitation [21]. The more advanced AWRs deliver comprehensive weather analysis and threat detection capability to pilots. These systems provide a long-range “clutter-free” weather display and enhanced effectiveness as a threat detector. Capabilities such as automatic scan operation, geographic weather correlation, overflight protection, and turbulence detection depict weather and weather related hazard events for the pilots. Turbulence detection provides flight crew with turbulence detection and alerting capability out to 40 nautical miles. Modern AWRs systems automatically give pilots a complete picture of weather while eliminating the requirement to manually adjust the radar. These systems automatically scan ahead of the aircraft and combine the returns through digital processing and analysis algorithms to display precipitation rates and the weather threats. This leads to have an accurate depiction of weather and turbulence hazards as well as significant reduction of flight deck workload and training for pilots [22]. AWR equipment supports the safe passage of an aircraft in the vicinity of turbulent weather conditions, and avoids penetration of aircraft into hazardous weather. It also provides timely warnings of rapidly changing weather conditions as an aid to in-flight route planning. In addition, such equipment allows maintaining contact with geographic features, such as shorelines, as a supplement to navigational orientation. Annex 6, Part I, Chapter 6, 6.11, recommends that aircraft operating in areas with potentially hazardous weather conditions be equipped with airborne weather radar. The ICAO policy (Appendix C to the Report of the Communications/Operations (COM/OPS) Divisional Meeting (1985) (Doc 9464) refers) is to retain the allocation without changes [4 pp. 7-128]. Airborne weather radar is considered to be a safety-critical instrument assisting pilots in deviating from potential hazardous weather conditions and detecting wind shear and microbursts [4 pp. 7-128]. The existence of AWR is of a crucial importance that these radars have irreplaceable position in informing the pilot of the meteorological situation ahead of the flying aircraft [19]. Consequently, the carriage of AWR is a mandatory requirement in many countries [4 pp. 7-134]. The radar antenna of AWR is typically located in the nose of the aircraft. Signals from the antenna are processed by a computer and presented on a screen, which may be viewed by the pilots. Droplet size is a good indicator of strong updrafts within cumulonimbus clouds, associated turbulence, and is indicated on the screen by patterns, color-coded for intensity [21]. AWR globally uses the band 5350 – 5470 and 9300 – 9500 MHz. The band 5350–5470 MHz is used on larger aircraft which permit the installation of larger antennas. In this band, RF waves penetrate dense moisture better than in the higher frequency bands. Many aircraft are equipped with this system [4 pp. 7-128]. The band 9300 – 9500 MHz is used extensively by aeronautical, maritime (land-based and shipborne) and national defense radar systems. They cater for shorter-range surveillance and precision functions up to a 50 km range [4 pp. 7-134]. AWRs, which require greater directivity, operate in the IEEE C-band (4-8 GHz) as well as in the X-band (8-12 GHz). The choice between the two bands reflects a dual trade-off. One is between storm penetration and scattering. If scattering is too severe, the radar will not penetrate deeply enough into a storm to see its full extent. Yet, if too little energy is scattered back to the radar, storms will not be visible at all. The other trade-off is between storm penetration and equipment size. C-band radars, providing better penetration, hence longer-range performance, are primarily used by commercial aircraft. X-band radars, providing adequate performance in smaller packages, are widely used by private aircraft. Band selection is a function of the trade-offs between range reflectivity and cost which vary as a function of the physics of rain attenuation [23 pp. 89]. AWR shorter wavelength has got a more important role for detection of storm clouds. In this role, the frequency band 9345–9375 MHz has been coordinated with other users within ITU-R as the agreed aeronautical airborne frequencies for this purpose. This band provides for a narrower beam than AWR operating at 5.3 GHz and, therefore, provides a better resolution and less ground clutter. Although the 5 GHz band is generally preferred, 70 per cent of aircraft use weather radar operating in the band 9345–9375 MHz [4 pp. 7-134]. Specification of “IntuVue (RDR-4000) Weather Radar” developed by Honeywell and “RTA-4100 MultiScan Weather Radar” developed by Rockwell Collins are brought as a modern example of airborne weather radars in tables 5 and 6.

3.2. Radio Altimeter (RA)

RA, also known as electronic altimeter, reflection altimeter, Radar Altimeter, Low Range Radio Altimeter (LRRA) is an airborne electronic device used for pilotage and navigation of aircraft in all phases of flight. The basic function of an aircraft RA is to provide terrain clearance directly beneath the aircraft, particularly in mountainous areas and during bad-weather landings [24]. Early RAs determined altitude by simply measuring the time between transmission of a radio signal from the aircraft and reception of the reflected signal, in contrast to a barometric altimeter, which provides the distance above a defined datum, usually mean sea level [25]. In contrast, not only does modern RAs measure the height of the aircraft above terrain, but they also measure the terrain characteristics with a high degree of accuracy. This implies high precision in the radar measurements, and therefore requires performance far greater than a conventional radar, in particular for classic radar range measurements. RA emits a pulse towards the Earth’s surface. The time which elapses from the transmission of a pulse to the reception of its echo reflected off the Earth’s surface is proportional to the aircraft’s altitude. The magnitude and shape of the echoes of pulses emitted toward the earth’s surface contain information about the characteristics of the surface which caused the reflection. Surfaces that are not homogeneous, or contain discontinuities or significant slopes make accurate interpretation more difficult. The best results are obtained over the ocean, which is spatially homogeneous, and has a surface that conforms to known statistics [26]. Main functions of RA include the measurement of vertical rate of climb or descent and low altitude warnings. RAs are also essential parts of many blind-landing and automatic navigation systems. In civil aviation, they are designed to support automatic landing, flare, and touchdown computations. When landing by ILS CAT III, once above the runway, the aircraft’s bottom-mounted RA measures altitude, and either the electronics or the pilot accomplishes the subsequent flare maneuver [24]. In this usage, RA is a tool to help minimize the risk of Controlled Flight Into Terrain (CFIT), because it provides an independent warning of proximity to the ground, regardless of any navigational uncertainty or error, e.g. mis-setting of the barometric altimeter sub-scale [25].

Table 5: Specification of IntuVue (RDR-4000) Weather Radar

Specifications	
Frequency	9.375 GHz
Input power	115 VAC (96-134 VAC) 360 Hz-800 Hz
Noise figure	1.9 dB
Power dissipated	150 VA nom
Minimum discernible signal	-124 dBm
Azimuth coverage (Weather)	+/- 80 degs
Azimuth coverage (Windshear)	+/- 40 degs
Gain for 18” antenna	31 dBi nom.
Beamwidth (18” antenna)	5.6 degrees

Table 6: Specification of RTA-4100 MultiScan Weather Radar

Specifications	
Frequency	9.45 - 9.49 GHz
Peak power	50 watts nominal
PRF	120 to 1,800 pps
Pulse widths	3.4 to 55 µs
Noise figure	3.8 dB
Bandwidth	32 MHz
Minimum discernible signal	-126 dBm
First side lobe	-30 dB
Input power	28 V dc ±20%
Power dissipated	70 watts or les
Antenna Gain for 18” antenna	30.5 (dB)
Beam Width (18” antenna)	5.7 (deg.)
Performance Index (18” antenna)	230.6
Avoidance Range (18” antenna)	461(nm)

Another application of RA is for map-matching, also called terrain contour navigation, which is a type of Terrain Reference Navigation (TRN). Here, the profile of the terrain is measured by using the readings of both a baro-inertial altimeter calibrated for altitude above Mean Sea Level (MSL), and a RA measuring height above the terrain. An on-board computer calculates the autocorrelation function between the measured profile and each of many stored profiles on possible parallel paths that can be taken by the vehicle [24]. In almost all RAs, the display of radio height ceases when an aircraft climbs through 2500' AGL and recommences when it descends through 2500' AGL. This is confirmed visually by the appearance/disappearance of an 'OFF' flag and emergence of a pointer from behind a mask or activation of a digital display [25]. RAs may be classified based on the frequency bands over which they operate. Radio altimeters normally work in the IEEE C-band, Ka-band, or, for more advanced sea-level measurement, S-band [2]. They comprise microwave, millimeter-wave, laser, and radioactive altimeters, though these delineations are rather rough because each waveband is very broad. For example, the frequency band 4.2 to 4.4 GHz in the microwave C-band is assigned to aircraft RAs. This frequency band is high enough to result in small-sized antennas being able to produce a 40° to 50° beam but is sufficiently low so that rain attenuation and backscatter have no significant range limiting effects [24]. For the applications of RA, a good interference rejection performance is essential. Integrity standards of the order of one failure in 1019 operations are not uncommon.

The use of a wide frequency band is an essential feature in effective designs to achieve high orders of interference rejection and freedom from disruptive effects due to the high levels of pollution of the radio environment which exist in densely populated areas. Studies have determined the necessity for the retention of the existing 200 MHz of spectrum to meet the exacting requirements of high accuracy with good all-round performance [4 - Attachment G pp.43].

Specification of "ALT-1000 Radio Altimeter System" developed by Rockwell Collins is brought as an example of RA in table 7.

Table 7: Specification of RTA-1000 MultiScan Weather Radar

Specifications	
RF center Freq.	4.3 GHz
Input power	3o W nom.
Off scale voltage	+18 ±0.5 V dc
Weight	2.04 kg (4.5 lb.) nominal
Time constant	0.09 ± 0.01 s
Temperature range (operating)	–55 to +70 °C
Temperature range (storage)	–55 to +85 °C
Altitude (continuous operation)	–1000 to +70 000 ft
Altitude (Over pressure)	–15 000 ft
Altitude (decompression)	+70 000 ft

4. Concluding Remarks

In this paper, both ground-based and airborne civil aviation radar systems were classified in sub-sections regarding to the duty of these systems. For each category, how these systems work and what their specifications are was discussed. An example of the latest radar systems hired by different countries in each category was finally given to provide a better scope.

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